Paper and Board
Industry Advisory
Committee

Ionising radiations

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Preface

This guidance has been produced by the Paper and Board Industry Advisory Committee (IAC) to assist mills in meeting their legal obligation to avoid risks to health in the use of ionising radiations. It should not be considered as either exhaustive or providing the only methods of meeting the obligation. This guidance has been prepared in consultation with the Health and Safety Executive (HSE) and should be read in conjunction with the Health and Safety at Work etc Act 1974 and other legislation referred to at paras 42 to 47. The Paper and Board IAC will review the interpretation and development of this guidance.

To prepare the guidance a subcommittee was appointed in 1980. Its terms of reference were to formulate guidance for presentation to the IAC on standards for the precautions to be adopted in the use of radioactive gauges on papermaking machines and other associated uses of radioactive substances in the paper making and conversion processes.

Introduction

1 The purpose of this guidance is to provide uniform, practicable and comprehensive advice to the paper and board industry on protecting persons from exposure to ionising radiations. It will be of particular interest to managers, safety advisers, safety representatives, machine men, instrument technicians and laboratory staff.

2 The industry is a large scale user of ionising radiations for controlling production processes and monitoring the quality of the product. The uses include substance gauges (often known as thickness gauges) used in both traversing and fixed position modes in manufacture and conversion, profile gauges and level gauges, radiography of the sheet material for quality control, elimination of static electricity from the product and smoke detectors used in fire control systems. This guidance does not cover site radiography using portable equipment. For further information on this subject, reference may be made to the *Code of practice for site radiography*, published by Kluwer Harrap Handbooks Ltd, 539 London Road, Isleworth, TW7 4DA.

3 The first part of this guidance is concerned with general background information on the subject. Advice on specific uses of ionising radiations in the industry, as described above, is contained in paras 47 to 108. Technical terms are defined in the glossary at the end. Such terms are asterisked * the first time they appear in the text.

Population exposure

4 All matter is composed of extremely large numbers of small units called atoms. They are the smallest part of elements* capable of independent existence, and an atom is approximately a ten millionth part of a millimetre in diameter. Each atom can be considered as having a central nucleus surrounded by electrons* continuously orbiting around it. The nucleus consists of protons* which have a positive electrical charge and neutrons* which have no electric charge. The electrons carry a negative electrical charge and the force of attraction between these and the protons maintains the structure of the atom. The numbers of protons and neutrons in the nucleus and the number of electrons surrounding it are different for every chemical element.

5 If extra energy in the form of a nuclear particle of certain types of ray reaches an atom, the energy deposited upsets the balance between the nucleus and electrons. One or more of the electrons may separate from the atom and this is the process of ionisation*. Radioactive material continually emits nuclear particles and/or rays which transfer energy and by the mechanism of ionisation can cause damage to human tissue.

6 All living things have been continually exposed to naturally occurring sources of ionising radiation from rock, the sea, space and even their own tissues. The amount of this radiation exposure depends on several factors and prior to the development of manmade sources and machines capable of emitting ionising radiations came solely from natural sources. For example, a person living in Hampshire where the rock is primarily calcareous is exposed to between 35 and 55 millirems* (0.35 and 0.55 mSv*) per year throughout life from the rock alone, whereas a person in Aberdeenshire where the rock is mainly granitic would receive between 50 and 150 millirems (0.5 and 1.5 mSv) per year from that source.

7 The average annual radiation dose for persons resident in the United Kingdom from both natural and manmade sources is now approximately 239 millirems (2.39 mSv) per year. The contribution from each source is given at Table 1, which is taken from the second edition of *Living with Radiation* published by the National Radiological Protection Board.

8 This guidance is intended to ensure that process operators and the general workforce in the paper industry are not exposed to levels of radiation which require them to be classified (see subpara (c) below and para 32) or to be subject to personal monitoring and medical surveillance. If the advice is followed, then these persons will be exposed to similar levels of radiation to those shown in Table 1. Usual practice is to set the following limits for levels of radiation exposure:

(a) individual members of the general public — not more than 500 millirem (5mSv) per year.

(b) non-classified occupationally exposed — not more than 1500 millirem (15 mSv) per year. This is equivalent to a dose rate of 0.75 millirem (7.5 μSv)

Source	*Average dose in millirems per year (1 millirem = 10 μSv)*
Radon decay products	80
Cosmic radiation	31
Rocks and building materials	38
Body constituents (mostly potassium 40)	37
Medical (mainly diagnostic)	50
Weapon fall out	1
Miscellaneous (air travel, watches etc)	0.8
Disposal of radioactive waste	0.3
Occupational exposure	0.9
Total	**239**

Table 1 Radiation doses from everyday sources

per hour based on an eight hour day, five day week, 50 week working year;

(c) classified occupationally exposed — not more than 5000 millirem (50 mSv) per year. This is equivalent to 2.5 millirem (25 μSv) per working hour.

9 It should be appreciated that a person who voluntarily has a chest X-ray* examination or a dental X-ray will receive comparatively high doses of radiation. A chest X-ray with modern equipment may result in a 20 millirem (200 μSv) dose while very old equipment could result in a higher dose. Health and safety at work legislation does not take account of radiation doses properly administered for medical purposes, as the person exposed is expected to benefit directly from such exposure by improved diagnosis or treatment. However, it should be remembered that the body reacts to all ionising radiation received regardless of its purpose and it is the total dose which determines what the effect may be.

Types of radiation

10 The ionising radiations used in the paper and board industry include the radiations emitted by radioactive isotopes (sometimes known as radio nuclides) and X-ray radiation emitted by electrical machines.

11 All atoms of an element have the same chemical properties but are not necessarily identical. They may have different weights, with the heavier atoms containing more neutrons than the lighter atoms. These different types of atoms are isotopes of the element and they differ only in the number of neutrons they possess.

12 Radioactive isotopes or radioisotopes are isotopes whose nuclei contain either more or fewer neutrons than are present in the stable isotopes of the element. They are made by adding neutrons by irradiation of the natural element in a nuclear reactor or by knocking out neutrons using an electrical machine such as a cyclotron.

13 Radioactive nuclei are unstable and change to stable forms by means of radioactive decay. During this decay one or more kinds of radiation will be emitted — alpha particles*, beta particles*, gamma rays* or X-rays. A further type of radiation, bremmsstrahlung*, can be generated when beta particles are slowed down passing through a dense material. It is these radiations emitted during radioactive decay which make radioisotopes useful in industry, in medicine and for research.

14 The types of radiations emitted by the sources commonly used in the paper and board industries are listed in Table 2. The information was obtained from published data.

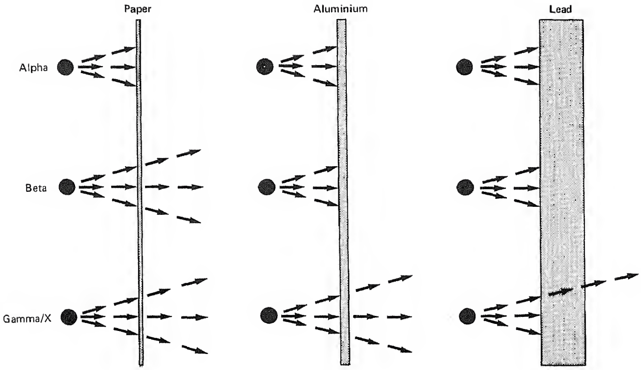
15 The different types of radiations have different penetrating powers as shown in Fig 1. The figure is purely diagrammatic and the thickness of lines shows the relative densities of the materials, not the actual dimensions.

16 Although ionising radiations cannot be detected by any of the human senses (sight, touch, smell, hearing, taste) they can be detected using specially designed instruments. It is therefore possible to measure the quantity of radiation passing through a material, for example a web of paper, and compare this with the quantity of radiation leaving the source and thus determine the thickness (substance) of that paper web. Alpha and beta particles cause intense ionisation of air (that means that they break the air molecules into

Radioisotope	*Useful type of radiation*	*Energy of radiation (MeV)**	*Half life* (years)*	*Application*	*Typical source activities (1 curie* = 37G Bq*)*
Iron 55	X-ray	0.006	2.7	thickness gauges	50 to 100 millicuries
Nickel 63	Beta	0.066	100	thickness gauges	100 millicuries
Krypton 85	Beta	(0.158 (0.672	10.73	thickness gauges	10 millicuries to 2 curies
Promethium 147	Beta	(0.103 (0.225	2.62	thickness gauges	50 to 400 millicuries
Strontium 90	Beta	2.274	28.6	thickness gauges	10 to 100 millicuries
Thallium 204	Beta	0.763	3.78	thickness gauges	20 to 200 millicuries
Americium 241	(Alpha	5.5	433	smoke detectors	few microcuries
	(Gamma	0.060		thickness gauges	500 millicuries
Caesium 137	Gamma	0.662	30.17	level gauges	50 to 100 millicuries
Cobalt 60	Gamma	(1.17 (1.33	5.27	level gauges	100 millicuries
Polonium 210	Alpha	5.305	138 days	static eliminators	Up to 1 curie
Carbon 14	Beta	0.15	5760	radiography	200 millicuries
Radium 226	(Beta	0.277		thickness gauges	10 microcuries
	(Gamma	4.781	1600	thickness gauges	100 millicuries
	(Alpha	4.598		smoke detectors	0.5 microcuries

Table 2 Common sources of radiation in the paper and board industry

Fig 1 Penetrating powers of different radiations



positively and negatively charged particles or ions) and it is this property which makes them so useful in static elimination devices and in smoke detectors. Although the radiations emitted by radioisotope sources can damage living cells and tissues, they cannot make anything or anybody exposed to them radioactive.

17 The majority of radiation sources used in the paper and board industry consist of a few grams or milligrams of radioisotope material enclosed in a protective case, usually of metal and often made of stainless steel and sealed by welding. The protective case is designed to retain the radioactive material so that the source doesnot leak but will efficiently emit the required radiation. Such radiation sources are known as sealed sources.

18 Sources in which the radioactive material is not completely contained in a protective case are unsealed sources. Examples are solutions of radioactive materials, materials in loose powder form, etc. Unsealed sources are rarely used for process control in the paper and board industry.

Effect of exposure

19 Exposure to ionising radiations can result in interference with the structure of atoms because of ionisation. The extent of this depends upon the dose received, the type of radiation and the energy of that radiation. In the case of humans, such exposure may result in some atoms of the matter contained within human cells behaving in an abnormal manner. This can result in complete destruction of these cells or interference with their normal method of reproduction. These effects are termed somatic. When large numbers of cells are destroyed the effect can usually be soon seen; where there is interference with normal cell reproduction, the effect is generally long term and can result in the development of cancers.

20 When the exposure to radiation results in cells not reproducing themselves in an identical form, because the genetic material is altered, the damage can result in the development of hereditary defects in subsequent generations. This is termed the genetic effect. The somatic effect therefore concerns individuals, whereas the genetic effect is of concern to society as a whole.

21 Gamma and X-ray radiation of sufficient energy can penetrate and pass through the body when it is exposed to such radiation sources. The hazard is thus both external and internal and can be a somatic and, if the reproductive organs are involved, a genetic risk.

22 Beta radiation has relatively little penetrating power and the hazard from such radiation external to the body is only to the surface areas and is a somatic risk only. Ingestion, inhalation or absorption of the beta-emitting substance itself into the body becomes an internal exposure hazard and can be a somatic and, in some situations, a genetic risk.

23 Most alpha radiation is stopped completely by the body's skin and therefore presents little or no external radiation hazard and no external somatic risk. Ingestion, inhalation or absorption of the alpha emitting substance into the body is a significant internal exposure hazard and has both somatic and genetic risks.

24 It is prudent to assume that there is some risk from any dose of radiation above the zero level and that risks to health vary with the dose of radiation received. It is recognised that exposure continuously at the rate of 5000 millirems (50 mSv) per year throughout the whole of a person's working life would lead to an increased probability of the development of cancers.

25 Legislation in Great Britain has followed the recommendations of the International Commission on Radiological Protection. Persons liable to receive more than 1500 millirems (15 mSv) per year from their work exposure need to be designated as classified workers and are then subject to medical supervision and dose monitoring throughout their working life in such employment.

26 Since 161, a total of seven classified workers in the paper and board industry have received radiation doses marginally above the legally permitted level for classified workers in the course of a year. Across industry as a whole, in workplaces subject to the Factories Act 1961, 560 classified workers have been overexposed in the same period. These figures come from the published annual reports of HM Chief Inspector of Factories.

Principles of protection

27 A basic concept of radiologicalprotection and hence the regulatory control to achieve it is to keep the radiation dose as low as reasonably practicable. Methods of achieving this protection include minimum sources, collimation, maximum distance from source, and appropriate shielding.These methods are discussed in the following paragraphs, together with medical supervision.

28 The radiation source should be of the lowest activity and energy necessary for the intended purpose taking into account the performance required and the need to avoid replacing sources too often.The latter can result in unnecessary frequent exposure.

29 A radiation source emits radiation in all directions and so the source holder should be designated to ensure that radiation is shielded off except in the desired direction through a 'window'. This radiation should be adequately collimated, to ensure that it is directed perpendicular to the window as a useful beam aligned so that it does not spread appreciably.

30 The radiationsource should be mounted as far away as reasonably practicable from any normal working area, and, wherever possible,the beam directed away from that area. The radiation dose rate varies with the distance from the source according to the inverse square law. This means that if the distance is doubled,the dose rate will be reduced to a quarter of the original level; equally, if the distance from the source is halved, the dose rate will increase to four times the original level.

31 The requirements for shielding any source can be established from Table 3. The table lists the range of sources and activities found in the industry and gives the type and thickness of material generally used to reduce dose rate at any access point to less than 0.75 millirem (7.5 μSv) per hour. The information has been produced by HSE, adapted from theoretical values. In the case of beta emitters, the thickness of material quoted as necessary for shielding purposes is greater than that theoretically required because of the need for adequate physical strength to stand up to the mill environment. For gamma emitters, the thickness of shielding material quoted is less than that calculated from an unshielded source to take account of the shielding action of the source housing.

32 Medical supervision is required in circumstances where the foregoing methods of protection cannot continue to be provided during maintenance, repair or replacement of the radiation source equipment. Persons who might as a result be exposed during that work to a radiation dose rate of more than 0.75 millirems (7.5 μSv) per hour need to be made classified workers or,

	Activity		*Shielding material – thickness*		
	(Curies)		*in millimetres*		
Radioisotope	*1 curie = 37G Bq*	*Perspex*	*Aluminium*	*Steel*	*Lead*
† Krypton 85	2	6	3	1	—
Promethium 147	0.4	6	3	1	—
Thallium 204	0.2	6	3	1	—
† Strontium 90	0.1	6	3	3	—
Nickel 63	0.1	6	3	—	—
Iron 55	0.1	6	3	—	—
‡ Americium 241	0.5	6	3	—	—
† Caesium 137	0.1	—	—	35	15
Cobalt 60	0.1	—	—	60	40
Radium 226	0.05	—	—	50	30
Carbon 14	0.2	6	3	—	—

Table 3 Required thickness of materials for adequate shielding

Note † If bremsstrahlung radiation is being produced, a perspex shield may need to be backed with steel or lead. The necessity for this, and the thickness which will be required, can only be determined by measurement of the dose rate.

‡ When Americium 241 is incorporated into smoke detectors no further shielding to that provided by the smoke detector body is necessary.

alternatively, in certain circumstances, follow a scheme of work approved by HM Chief Inspector of Factories (see para 34) designed to ensure that the total radiation dose they receive does not exceed 1500 millirems (15 mSv) in a year.

33 Classification requires the person to undergo specific medical examinations and to wear some form of personal dose meter. A health register and dose record have to be maintained for each classified person and the dose record kept available for inspection by that person. The classified person may be subject to an annual medical examination dependent upon the radiation dose being received. No classified person should receive more than 5000 millirems (50 mSv) in a year and working methods and procedures need to be examined and reappraised whenever a classified person reaches a 1500 millirems (15 mSv) total dose.

34 Where the person is working under an approved scheme of work it should be appreciated that he will be allowed to be exposed up to an annual dose of 1500 millirems (15 mSv) without necessarily incurring any medical examination or personal dose monitoring, although these may be conditions of the approved scheme of work. The IAC considers that in the paper and board industry recourse to an approved scheme of work is not necessary. Where maintenance work involves exposure to a dose rate greater than 0.75 millirems (7.5 μSv) per hour, the workers would be classified, and adequate measures to prevent process operators and the general workforce being exposed to radiation levels significantly above natural background are easily achieved.

What an employer should do

35 The employer should ensure that:

(a) a suitable person is appointed and is readily available to advise on radiological protection and relevant legal requirements;

(b) the most suitable source of ionising radiations for the purpose required is used and that the minimum activity commensurate with satisfactory economic performance is employed;

(c) the source of ionising radiations is sited at a suitable position so as to restrict the potential of exposure to as few persons as it is reasonable to achieve;

(d) any source of ionising radiation is installed with adequate shielding so that during normal use no persons are exposed to radiation;

(e) the equipment is provided with suitable warning signals and notices, interlocked barriers and shielding as appropriate, and that these are all regularly maintained in an efficient state;

(f) those persons who might be exposed to ionising radiations during maintenance or repair work are classified and have been subject to medical examination, provided with suitable dosemeters and that records of medical examination and any radiation doses received are maintained;

(g) persons conducting such work are provided with such shielding as is reasonably practicable for their protection during that work. They should also have been informed of any risk involved, the precautions to be observed and the methods by which the work should best be carried out;

(h) all persons operating any machine or equipment in which a source of ionising radiation is installed have been informed of the precautions taken and instructed not to misuse or interfere with the equipment;

(i) suitable monitoring equipment is provided or is readily available;

(j) the location of each source of ionising radiation, the type of radiation, and its activity is always known by the keeping of an appropriate up to date record and the operation of a check procedure;

(k) the use and disuse of ionising radiations is notified to the enforcing authority and any loss, leakage or damage of a source and any incident where a person may have been unnecessarily exposed is notified to that authority and properly investigated;

(l) contingency plans have been made, and are familiar to all persons who need to know, to cater for accident situations such as fire, explosion or impact that may have interfered with the integrity of the source and any associated safety equipment. Paras 44 and 45 consider emergency procedures in more detail;

(m) persons other than his employees are not put to any risk to their health and safety as a result of his use of ionising radiations.

What an employee should do

36 The employee should:

(a) not interfere with or misuse any safety devices provided for his protection against exposure to ionising radiations;

(b) report immediately to his employer any failure of an interlock or warning signal, or damage to any shield or barrier;

(c) wear and use when necessary any safety equipment provided for his protection;

(d) operate and use the equipment only as instructed.

What a supplier, agent or installer should do

37 The supplier, agent or installer should:

(a) determine the use for which the equipment is intended and the position at which it is intended to be used;

(b) provide the most suitable source of ionising radiations for the purpose required;

(c) provide and/or install the equipment with appropriate shielding, barriers, interlocking arrangements, warning signals and notices (unless other arrangements have been made at the user's request, in writing, to transfer the responsibility to the user);

(d) ascertain where necessary that the equipment has been properly installed;

(e) provide information and instruction so that the equipment may be properly used without risk of exposure to ionising radiations.

Legal requirements

38 There are a number of legal requirements imposed on the use of ionising radiations. Of particular interest and importance to the paper and board industry are the following:

(a) Radioactive Substances Act 1960;

(b) Health and Safety at Work etc Act 1974;

(c) Ionising Radiations (Sealed Sources) Regulations 1969.

The regulations at (c) above are made under the Factories Act 1961. Under consideration at the present time is a new code of regulations which will be made under the Health and Safety at Work etc Act and based on the principles embodied in a European directive. The principal requirements of the new code of regulations are expected to be broadly the same as those of the 1969 regulations, which will be replaced. The advice contained in this guidance reflects the requirements of the existing and proposed regulations.

39 The following paragraphs are intended only as a summary of matters covered by the legislation. For further detail the legislation itself should be consulted.

Radioactive Substances Act 1960

40 This Act was introduced to control the accumulation of radioactive waste, to create a register of users of radioactive materials and mobile radioactive apparatus and to set up a system in which radioactive materials can only be accumulated or disposed of with an authorisation granted by the enforcing authority on behalf of the Secretary of State. The Act is enforced by the Radiochemical Inspectorates of the Department of the Environment (England), Scottish Development Department (Scotland) and Welsh Office (Wales).

41 The Act requires users to:

(a) obtain a licence before radioactive materials can be stored or used;

(b) limit the quantity held;

(c) display the registration licence;

(d) arrange suitable storage;

(e) notify any loss or damage which might result in exposure of the public;

(f) obtain permission before the disposal of radioactive materials.

Health and Safety at Work Act 1974

42 This Act is enforced by HSE in paper mills. Particular attention should be paid to the sections summarised in this paragraph:

(a) Section 2 places a general duty on an employer to ensure, so far as is reasonably practicable, the health, safety and welfare of his employees. He should also consult his employees' safety representatives concerning arrangements on health and safety matters, devise and implement safe systems of work, prepare and publicise a written safety policy with arrangements for implementing it and, upon request, establish a safety committee;

(b) Section 3 places a general duty on an employer to ensure that his undertaking does not endanger anyone not in his employment and to provide, in certain circumstances, information to the public regarding potential hazards to health and safety;

(c) Section 4 places a duty on persons responsible for workplaces to ensure that the premises themselves, together with any plant and machinery in them, do not endanger people using them;

(d) Section 6 places duties on manufacturers, designers, importers or suppliers of articles or substances for use at the workplace, to ensure that they are as safe as reasonably practicable when used in accordance with any necessary information, which also must be supplied;

(e) Section 7 places a duty on employees to ensure that they do not place themselves or others at risk in carrying out their work activities, and to cooperate with employers in meeting statutory requirements;

(f) Section 8 places a general duty on all persons not to misuse anything provided in the interests of health and safety.

Ionising Radiations Regulations

43 These regulations apply to the use and storage of radioactive material and to machines and apparatus which emit ionising radiations. (See para 38 for their status). They too are enforced by HSE. The regulations set requirements for:

(a) notification (the enforcing authority must be informed of use, disuse, loss, damage or over-exposure);

(b) limitation of dose (exposure should be limited to the minimum reasonably practicable level and not in excess of the specified dose limit);

(c) designation of radiation areas;

(d) appointment of radiation advisers and supervisors;

(e) instruction and training;

(f) basic principles of protection, including restriction of exposure and adequate shielding. If dose rates in excess of 0.75 millirem (7.5 μSv) per hour exist then radiological supervision is required;

(g) radiological supervision (this involves the designation of classified workers, who will require dosemeters, dose records, transfer records and medical supervision);

(h) organisation of work (this includes transport, handling and monitoring);

(i) investigation of incidents.

Emergency procedures

44 The employer should make such plans as are necessary, and ensure that the appropriate staff are made aware of them, and also have available any equipment necessary, to cater for a fire, explosion or impact accident involving a source of ionising radiation. These plans should be in the form of written procedures, regularly updated.

45 The following matters need to be considered in such plans:

(a) exclusion from the area concerned of all persons except classified workers and persons otherwise authorised;

(b) notification to the person appointed to advise on radiological protection or any other organisation retained to advise;

(c) monitoring to determine the extent of a radiation area or contaminated* area;

(d) provision of emergency shielding in the form of sand bags, lead sheet or bags of lead shot;

(e) identification of persons who might have been exposed to radiation or who might have ingested, inhaled or otherwise absorbed radioactive material;

(f) medical examination of and the provision of biological samples from those concerned if necessary;

(g) notification of the incident to the enforcing authority.

Substance gauges

46 The major application of gauges incorporating a source of ionising radiations is for the continuous substance measurement of the product on the making machine. The term 'thickness' is sometimes used instead of 'substance'. Such gauges are generally used in the transmission mode with a source of beta radiation below the paper web and a detector directly above it, the two being separated by an air gap. This gap is rarely less than 25 mm and is more often 75 mm in depth. In this mode the density of the web is calculated by comparing the amount of radiation emitted with that received by the detector after passing through the web.

47 Some substance gauges operate on the back scatter principle in which the source and detector are in a single housing and the thickness is determined by the proportion of radiation reflected back from the web in relation to the amount emitted.

48 Several gauging systems now incorporate a low energy X-ray generator in addittion to a source of beta radiation and can, by careful selection of the X-ray energy (normally in the range of 5.8 keV to 8 keV), determine the amount of some fillers in the web material in addittion to the density measured by the beta emitter.

Fixed position substance gauges

49 Only limited process information can be obtained from gauges used in a fixed, or static, position and, although they may be positioned to monitor any part of the web; they are generally employed at the centre only. Their use is diminishing. The majority of fixed position gauges operate on the back scatter principle although transmission types are sometimes used. Fixed position gauges generally utilise either krypton 85 or thallium 204 radioisotopes with activities of up to 100 millicuries (3.7 G Bq). However both radium 226 or strontium 90 isotopes are also used sometimes and will create difficulties in shielding and use. The use of the latter two radioisotopes rarely offers any advantage over krypton.

Traversing substance gauges

50 The present generation of traversing gauges generally uses sources of krypton 85 although the radioisotopes thallium 204, strontium 90 and radium 226 are sometimes used. Because shielding is more difficult to achieve with high energy beta emitters such as strontium 90, and the same problem arises with the gamma complement from radium 226, the use of these two radioisotopes has significantly declined.

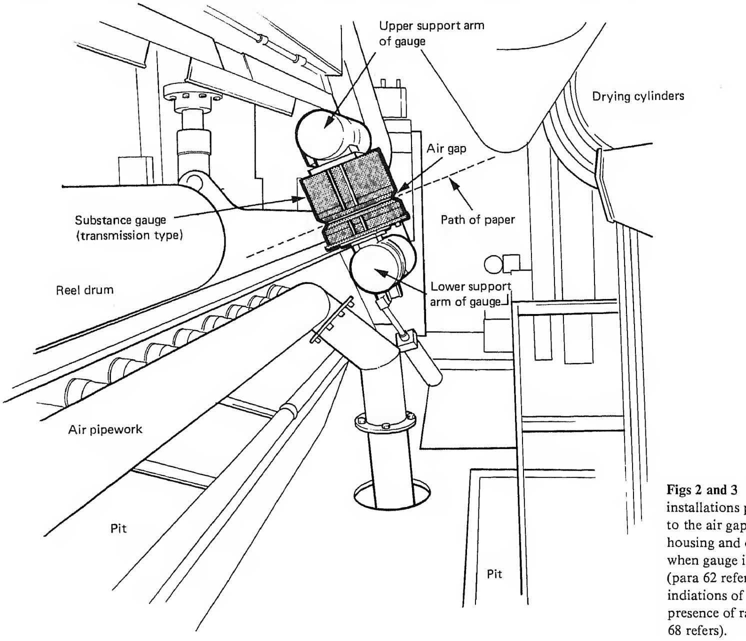
51 The gauge traverses across the web and the speed of traverse and interval between each traverse can be varied to suit the machine and process. Typically traversing is continuous with each pass taking one to two minutes. The system electronics require periodic standardisation. For this to be carried out the gauge moves off-sheet to the backside and dwells there for up to one minute with the shutter open and no material present in the measuring head. For most current measuring systems a central computer controls speed and frequency of traverse as well as standardisation interval. There is a facility for manual control overriding the computer.

Hazards from substance gauges

52 A radioisotope radiation source cannot be switched off and so there is potentially a continuous hazard. X-ray machines, where incorporated (see para 48), generate radiation dose rates of the order of hundreds of rems (thousands of mSv) in the direct beam, with lower rates away from the beam due to scattered (secondary) radiation, only when switched on. The hazard can be eliminated simply by switching the machine off.

53 With all gauges, when the shutter is open, the dose rate within the air gap through which the paper passes between source container and detector may be of the order of 5 to 10 rems (50 to 100 mSv) per hour towards the edge of the gap and several tens of rems (several times 10 mSv) per hour directly over the source. Because of scattered radiation the doserate at the edge of the gap can be as high as 120 millirems (1.2 mSv) per hour even though the primary beam is well collimated.

2


Upper support arm of gauge
Drying cylinders
Air gap
Path of paper
Substance gauge (transmission type)
Reel drum
Lower support arm of gauge
Air pipework
Pit
Pit

Figs 2 and 3 Unacceptable installations permitting free access to the air gap between source housing and detector, particularly when gauge is at limit of traverse (para 62 refers). There are no indiations of shutter state or presence of radiation areas (para 68 refers).

Methods of ensuring safety at substance gauges

54 Precautions must therefore be taken to ensure that operators cannot have access to areas where such high radiation doses arise. The dose rate at any point to which an operator has access should be below 0.75 millirems (7.5 μSv) per hour. This may be achieved by careful positioning of the radiation equipment, by the provision of addititional shielding and by the installation of interlocks and warning signals. Figures 2 to 8 show various mill installations, some acceptable, some not.

Positioning

55 Wherever reasonably practicable the radiation source should be mounted remote from the operator's routine working area and orientated so that the useful beam of radiation is directed away from occupied areas. Ideally a traversing substance gauge would be mounted above head height with the radiation source below a horizontal web run and aiming upwards.

56 In most cases, however, this ideal will not be achievable because of the nature of the machine and it will then be necessary either to provide barriers to prevent access to the source or addititional shielding around the source. To avoid the need for machine operators to place their hands in the vicinity of the radiation source the tail of the web should be fed through the 'O' frame (the structure across which the gauge is mounted) using a Sheahan rope, air jet, or other automatic means.

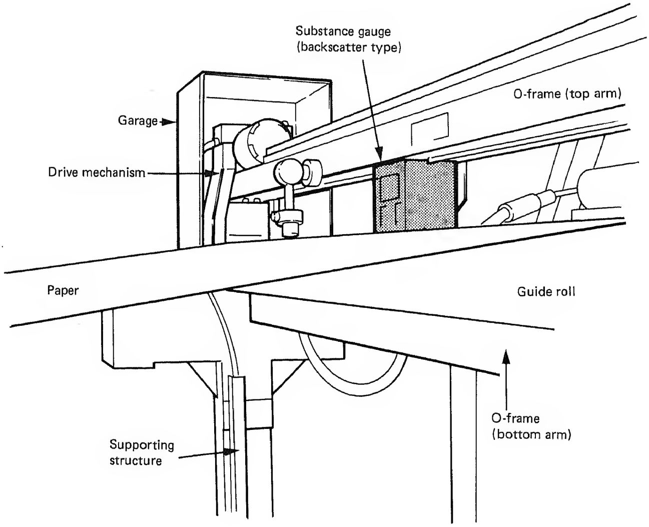
57 Where a fixed position substance gauge is positioned at the centre of the web, there is generally no need to provide shielding or barriers to prevent access while material is passing through the gauge. A monitor should be used to establish that the dose rate is below 0.75 millirems (7.5 μSv) per hour (see para 68). It is necessary to provide a safety device to automatically close the shutter if the paper breaks to ensure that no radiation hazard is created. The device is usually a dielectric or photoelectric detector.

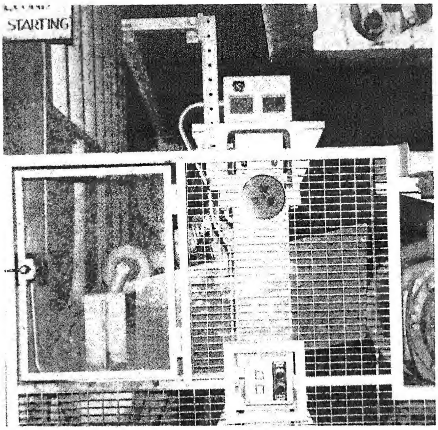
Barriers and interlocking

58 When it is not possible to position the substance gauge remote from the machine crews (and this will be the situation in most cases) it is usually necessary (see para 54) to provide a barrier to prevent access to the gauge. A wire mesh gate may be provided at either end of the 'O' frame of a traversing gauge. In some situations, a shield of perspex, aluminium or steel as appropriate may be necessary (see paras 31 and 61).

59 Since access to both the machine and the gauge will be necessary from time to time a gate or similar access should be provided in the barrier. So that this access can only be used when the radiation source is safe (X-ray machine switched off, and shutter closed) an interlock will be necessary between the access point and the radiation device. Opening the access should initiate closure of source shutter and with traversing substance gauges should also send the gauge to the 'off-web' (garage) position. The methods of operation of these interlocks should follow the recommendations set out in:

3





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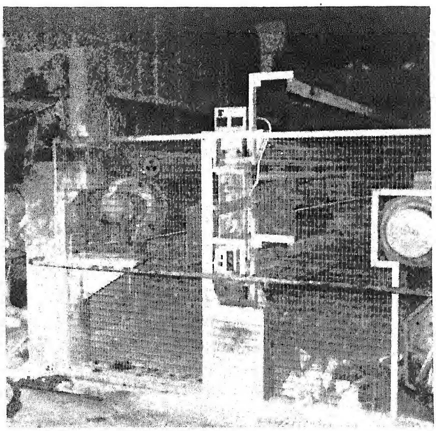


5

Figs 4 and 5 Acceptable methods of prevention of access to radiation areas during use by physical shielding and shielding by distance.

(a) BS 5304: 1975 *Safeguarding of Machinery* British Standards Institution;

(b) Health and Safety at Work Booklet No 24 *Electrical limit switches and their applications*. HMSO;

(c) *Electrical safety interlock systems* (D Hughes). Obtainable from Science Reviews Ltd, c/o 28 High Ash Drive, Leeds LS17 8RA.

It is particularly important that door interlocks are sufficiently robust to withstand the wear and tear to which they will be subjected.

60 Some traversing gauges are not provided with an effective shutter and such gauges should travel automatically off-web into a shielded 'garage' in the event of a web break or anyone entering the barriered area. The electrical circuits should be so arranged that whenever a shutter is closed, or gauge sent off-web, the shutter can only be opened again, or the gauge brought back on web, by initiation of the measuring sequence from the control console. If the console is remote from the gauge, the initiation of the sequence may be by local controls outside the barrier, after the access gate has been closed.

Shielding

61 The provision of shielding material may be used additionally or alternatively to the provision of a physical barrier. Additional shielding is generally necessary to stop the radiation which is scattered sideways through the air gap from the primary radiation beam. This scatter is a particular problem with traversing substance gauges as they approach the edge of the web. Reducing the air gap to a minimum may cut down the scatter.

62 Instead of providing barriers or shielding material at the sides of the machine, an alternative is to extend the top and bottom guide plates all round the gauge with 1 mm thick aluminium. This method can be very effective in stopping scattered radiation and preventing access to the air gap but cannot be used in many cases due to limitations of space on the 'O' frames. Figure 9 shows the principle (on page 12).

63 In situations where protection by distance cannot be achieved with wire mesh barriers, the shielding material can be either aluminium sheet or perspex. Whilst 2 mm of aluminium or 3 mm of perspex is sufficient to stop the radiation, the mechanical strength of these thicknesses is inadequate for mill conditions and thicknesses of 3 mm

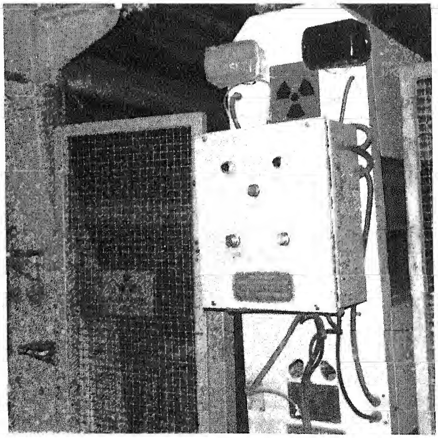
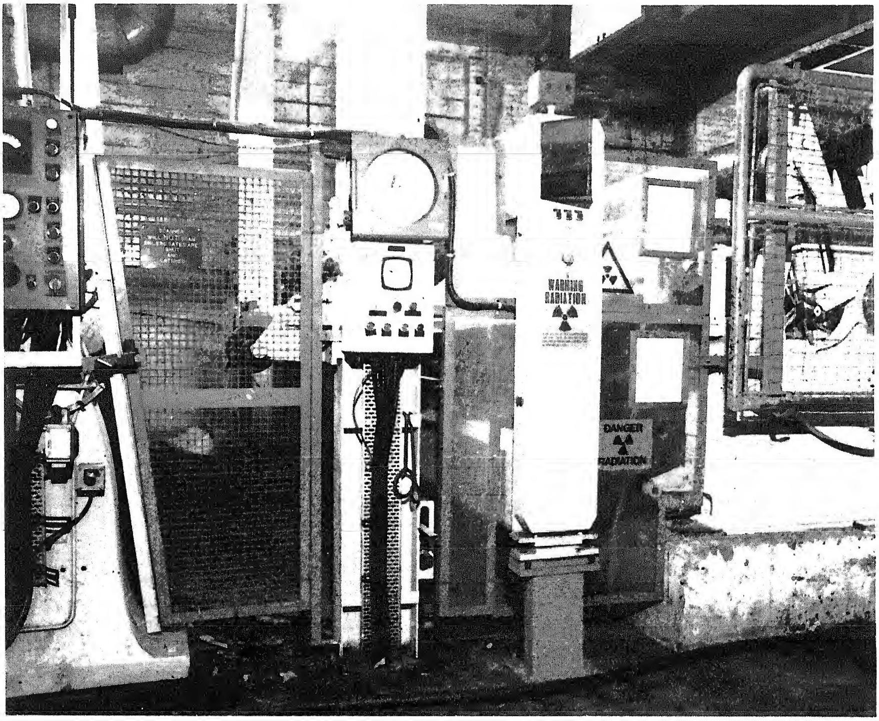


Fig 6



7

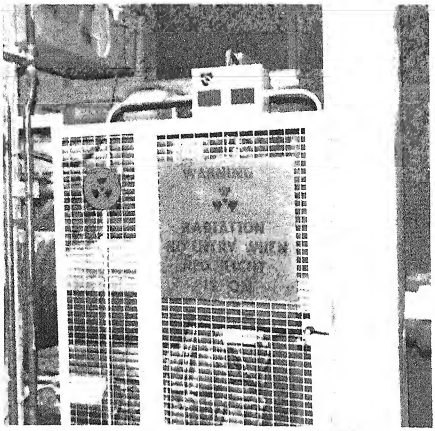
Figs 6, 7 and 8 Acceptable indicators of shutter state and radiation area warning notices.

and 6 mm respectively are recommended. Where a high energy beta emitter such as strontium 90 is used an outer layer of 1 mm of steel may be necessary to absorb the bremsstrahlung radiation.

Warning signals and notices

64 The state of any automatic shutter should be clearly indicated to persons approaching the source. If this is an electrically illuminated notice both 'open' and 'closed' legends should be provided such that one or the other indication is always illuminated when the gauge is in use. The electrical circuitry to operate these signals should be derived from the source shutter open and closed end-stops and not from the initiation circuits. This will avoid false indications if the shutter itself fails.

65 At substance gauges where X-rays are used addititional warning signals are necessary. These are required to indicate when X-rays are about to be



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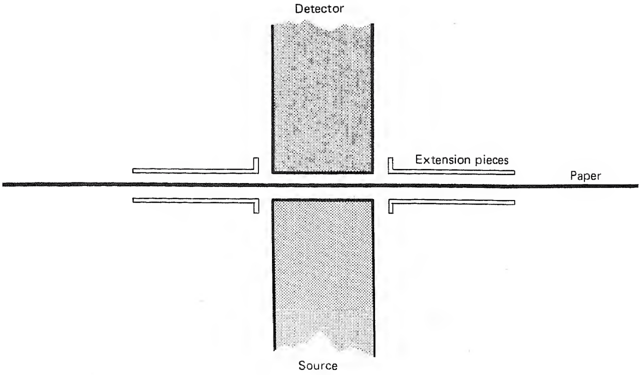

Fig 9 One simple method of shielding a substance gauge

produced, when they are produced, when the shutter is about to be opened and when it is open. These signals should be automatic and readily distinguished from each other. Illuminated legends stating 'X-rays ready', 'X-rays on', 'shutter closed' and 'shutter open' are suitable. If the X-ray machine is included in a gauge containing a radioisotope source there is no need for a separate 'X-ray ready' warning signal.

66 The boundary of any area enclosed by barriers or shielding should also display the international Trefoil symbol of radiation together with a notice forbidding entry whilst radiation is being emitted. Suitable wording for a notice is:

'RADIATION. KEEP OUT WHEN SHUTTER IS OPEN'

67 The presence of radioactive materials should be clearly marked by the international Trefoil symbol on the outer housing of every substance gauge so that any person approaching it is aware that it contains radioactive material. The symbol should be to the pattern of BS 3510: 1968. The type of material and its activity should also be labelled clearly.

Monitoring

68 A radiation monitor should be used to establish that the gauge is adequately shielded when first taken into use and subsequently for routine verification, particularly after any maintenance or repair which may have impaired or altered the original shielding. The monitor should be calibrated at the appropriate energy to measure the quantity of radiation likely to be present. A monitor incorporating a Geiger-Muller tube in a mobile probe is acceptable. The end window of the probe should preferably be not more than 25 mm in diameter so as to be capable of detecting and measuring narrow beam leaks. Figure 10 shows a monitor in use.

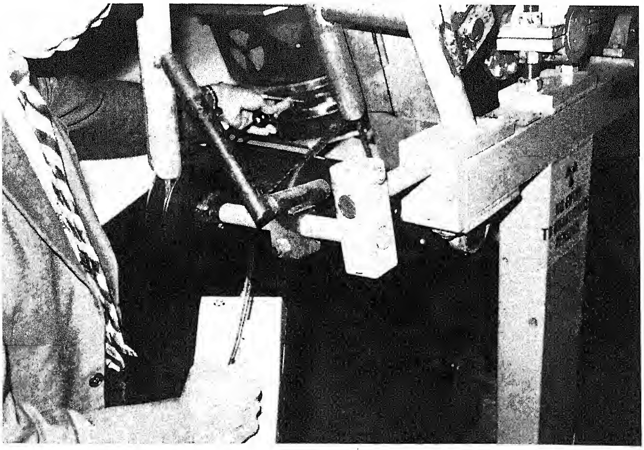

Fig 10 Monitor in use

Maintenance and repair

69 A check should be made that the shutter is closed, or the X-ray machine switched off, before starting any work on the housing. If it is not reasonably practicable to remove the source from its housing and transport it in a shielded state to a suitable store for work to be carried out, then the housing itself should be removed from the machine to a suitably barriered area to exclude unclassified workers.

70 Removal of any source from its housing, or its replacement, should only be carried out by using suitable long handled tongs. The person handling the source should preferably work from behind a perspex or other suitable screen to prevent head exposure. Gloves with a material density of at least 10 milligrams per square centimetre, such as household rubber gloves, should be worn. They will protect the hands adequately from beta radiation.

Level gauges

71 Level gauges are used to determine high and low levels of various stock materials and additives in chests, hoppers and closed vessels in the preparation end of the mill and are often installed at inaccessible positions. The source is usually mounted on one side of the vessel with the detector at the other. Due to the density of the material to be measured and the steel or concrete shell of the containing vessel, gamma-emitting radioisotopes such as cobalt 60 or caesium 137 with activities up to 100 millicuries (3.7 G Bq) are employed.

Hazard

72 A radioisotope radiation source cannot be switched off and so there is potentially a continuous hazard. The nature of the risk can be appreciated from the fact that the dose rate in the primary beam at 1 metre from a level gauge containing 100 millicuries (3.7 G Bq) of caesium 137 would be around 30 millirems (30 μSv) per hour if there was no intermediate shielding.

Methods of ensuring safety at level gauges

73 Precautions should therefore be taken to ensure that operators can never have access to areas where such radiation doses arise. The dose rate at any point to which an operator has access should be below 0.75 millirems (7.5 μSv) per hour. This may be achieved by careful positioning of the radiation equipment, by the provision of addititional shielding and by the installation of interlocks and warning signals.

Positioning

74 Wherever possible the radiation source should be mounted remote from the operator's routine working area and orientated so that the useful beam of radiation is directed away from occupied areas.

Barriers and interlocking

75 When it is not possible to position the level gauge remote from areas where people work it will be necessary to provide a barrier. A wire mesh fence may be erected around the gauge to prevent access. In some situations the barrier may need to be constructed of an appropriate shielding material (see paras 31 and 78).

76 Access to the level gauge and adjacent parts of the vessel it is associated with will be necessary from time to time and so a gate or similar access should be provided in the barrier. This access can only be used when the radiation source is safe (i.e. shutter closed) and so an interlock should be provided between access point and radiation device. Opening the access should cause the source shutter to close. The method of operation of the interlock should follow the recommendations set out in:

(a) BS 5304: 1975 *Safeguarding of machinery* British Standards Institution;

(b) Health and Safety at Work Booklet No 24 *Electrical limit switches and their application* HMSO;

(c) *Electrical safety interlock systems* (D Hughes); obtainable from Science Reviews Ltd, c/o 28 High Ash Drive, Leeds LS17 8RA.

77 It is particularly important that door interlocks are sufficiently robust to withstand the wear and tear to which they will be subjected. The electrical circuits should be so arranged that whenever a shutter has closed it can only be opened again by initiation of the measuring function from the control console.

Shielding

78 The provision of shielding material may be used additionally or alternatively to the provision of a barrier. Additional shielding may be necessary to stop the radiation which is scattered sideways from the primary radiation beam (para 31 refers).

Warning signals and notices

79 The state of any automatic source shutter should be clearly indicated to persons approaching the source. If this is an electrically illuminated notice both 'open' and 'closed' legends should be provided such that one or the other indication is always illuminated when the gauge is in use. The electrical circuitry to operate these signals

should be derived from the source shutter open and closed end stops and not from the initiation circuits. This will avoid false indication if the shutter itself fails to operate.

80 The boundary of any area enclosed by barriers or shielding should also display the international Trefoil symbol of radiation together with a notice forbidding entry whilst radiation is being emitted. Suitable wording for a notice is:

'RADIATION. KEEP OUT WHEN SHUTTER IS OPEN'

81 The presence of radioactive materials should be clearly marked by the international Trefoil symbol on the outer housing of every level gauge so that any person approaching it is aware that it contains radioactive material. The symbol should be to the pattern specified by BS 3510: 1968. The type of material and its activity should also be clearly marked.

Monitoring

82 A radiation monitor should be used to establish that the gauge is adequately shielded when first taken into use and subsequently for routine verification particularly after any maintenance or repair which may have impaired or altered the original shielding. The monitor should be calibrated at the appropriate energy to measure the quantity of radiation likely to be present. A monitor incorporating a Geiger-Muller tube in a mobile probe is acceptable. The end window of the probe should preferably be not more than 25 mm in diameter so as to be capable of detecting and measuring narrow beam leaks.

Maintenance and repair

83 Any person required to carry out maintenance, repair or part replacement on any level gauge and might be exposed to a dose rate of ionising radiation in excess of 0.75 millirems (7.5 μSv) per hour will need to be classified. He should be instructed as to the risks involved, the precautions to take, and the proper method of working.

84 A check should be made that the shutter is closed before starting any work on the housing. If it is not reasonably practicable to remove the source from its housing and transport it in a shielded state to a suitable store for work to be carried out, then the housing itself should be removed from the machine to a suitably barriered area to exclude unclassified workers.

85 Removal of any source from its housing, or its replacement, should only be carried out by using suitable long handled tongs. The person handling the source should preferably work from behind a suitable screen to prevent head or body exposure.

Profile gauges

86 Profile gauges are often used to assist in quality control. Due to the speed at which the paper passes through the measuring head while the gauge traverses across the deckle, some variations along and across the paper might not be detected by a thickness gauge. Profile gauges are a means of checking whether such variations are significant. A long strip of paper cut from the reel can be fed through the device to provide the required

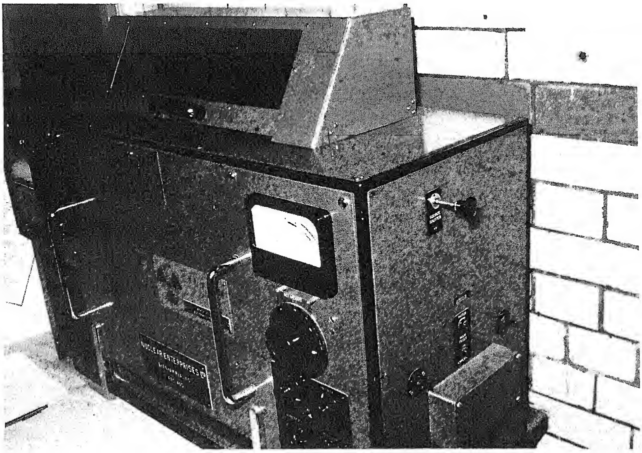

Fig 11 Typical profile gauge

information. Profile gauging systems usually consist of a source of up to 50 millicuries (1.85 G Bq) of thallium 204 or krypton 85 installed within a bench-mounted cabinet provided with a means of feeding a continuous strip of material through a narrow slit. Figure 11 shows a typical profile gauge.

Hazard

87 A radioisotope radiation source cannot be switched off and there is potentially a continuous hazard. Precautions should therefore be taken to ensure that operators never have access to parts of the profile gauging apparatus where radiation dose rates exceed 0.75 millirems (7.5 μSv) per hour. These include the provision of adequate shielding and the installation of suitable interlocks and warning signals.

Shielding and interlocking

88 The beta radiation emitted by the source in a profile gauge will be completely absorbed by the cabinet which serves as shielding. Additional shielding may be necessary at any openings in the cabinet. Access into the gauge housing will be necessary for feeding through the paper strip and the opening section of the cabinet must be interlocked with the source shutter. The interlocking should be arranged so that access is only possible with the shutter closed and the method of operation of the interlocking should follow the recommendation set out in:

(a) BS 5304: 1975 *Safeguarding of machinery* British Standards Institution;

(b) Health and Safety at Work Booklet No 24 *Electrical limit switches and their applications* HMSO;

(c) *Electrical safety interlock systems* (D Hughes); obtainable from Science Reviews Ltd, c/o 28 High Ash Drive, Leeds LS17 8RA.

89 It is particularly important that interlocks are sufficiently robust to withstand the wear and tear to which they will inevitably be subjected. The electrical circuits should be so arranged that whenever the shutter has closed it can only be opened again by initiation of the measuring function from the controls of the profile gauge.

Warning signals and notices

90 The state of the source shutter should be clearly indicated to persons approaching the source. If this is an electrically illuminated notice both 'open' and 'closed' legends should be provided such that one or the other indication is always illuminated when the gauge is in use. The electrical circuitry to operate these signals should be derived from the source shutter open and closed ends stops and not from the initiation circuits. This will avoid false indications if the shutter itself fails to operate.

91 The presence of radioactive materials should be clearly marked by the international Trefoil symbol on the outer housing of every profile gauge so that any person approaching it is aware that it contains radioactive material. This symbol should be to the pattern specified by BS 3510: 1968. The type of material and its activity should also be clearly marked.

Monitoring

92 A radiation monitor should be used to establish that the gauge is adequately shielded when first taken into use. It should subsequently be used for routine verification, particularly after any maintenance or repair which may have impaired or altered the original shielding. The monitor should be calibrated at the appropriate energy to measure the quantity of radiation likely to be present. A monitor incorporating a Geiger-Muller tube in a mobile probe is acceptable. The end window of the probe should preferably be not more than 25 mm in diameter so as to be capable of detecting and measuring narrow beam leaks.

Maintenance and repair

93 Any person required to carry out maintenance, repair or part replacement on any profile gauge and might be exposed to a dose rate of ionisong radiation in excess of 0.75 millirems (7.5 μSv) per hour will need to be classified. He should be instructed as to the risks involved, the precautions to take and the proper method of working.

94 A check should be made that the shutter is closed before starting any work on the cabinet. If it is not reasonably practicable to remove the source from the gauge and transport it in a shielded state to a suitable store for work to be carried out, then the profile gauge itself should be removed to a suitably barriered area to exclude unclassified workers.

95 Removal of any source from its housing or its replacement, should only be performed using long handled tongs suitable for the task. The person handling the source should preferably work from behind a perspex or other suitable screen to prevent head exposure. Gloves with a material density of at least 10 milligrams per square centimetre, such as household rubber gloves, should be worn. They will protect the hands against beta radiation.

Static eliminators

96 Friction generated during the manufacturing process can result in a charge of static electricity building up on the paper. This might, in some circumstances, cause a fire from the spark resulting when the static is discharged and can interfere with the subsequent processing of the paper. Mill employees may receive uncomfortable electric shocks if they touch the paper.

97 Static charges can be eliminated by providing an area of ionised air adjacent to the material. The radioisotope polonium 210, an alpha emitter, is used for this purpose — the activity ranging from 20 up to several hundred millicuries (720 MBq upwards). The radioisotope can be incorporated in bars, air nozzles and air blowers.

98 Static eliminator sources present few problems provided that they are not damaged. Alpha particles have a very short range in air and cannot penetrate the skin, so there is no external radiation hazard. Shielding of the eliminator is not therefore necessary. A radiation hazard will arise only if the radioactive material can enter the body, e.g. through a cut, or by swallowing or breathing in fragments.

99 The source is designed so that this cannot happen if the eliminator is undamaged. Static eliminators should be fixed to the machine only using the means provided and should never be cut, sawn, drilled, screwed or subject to chemical attacks. It is particularly important to avoid solvent contact where a static eliminator bar has been manufactured using adhesives. If the eliminator is involved in a severe fire or suffers any other damage it is possible that radioactive material might be released. The appropriate emergency procedures should be followed and the area of the machine where the eliminator is located should be barriered off until the integrity of the source has been checked.

100 The radioisotope material and its activity should be clearly marked, and its radioactivity made obvious to any person handling the static eliminator.

Radiography

101 Information regarding the distribution of filler material and the thickness of the paper over a large area is often required and this is generally obtained by the radiography of a sheet of the finished paper. The radioisotope carbon 14 incorporated in a polycarbonate sheet is generally used for this type of radiography. Carbon 14 is a beta emitter. In the form used, the radioisotope is considered to be an unsealed radioactive substance and extreme care has to be taken to avoid skin contact with the radioisotope containing material to prevent absorption via the skin.

102 The radioactive material should be installed in a cabinet to prevent contact and the paper for examination should be introduced remotely. Figure 12 shows a typical arrangement.

103 The presence of radioactive material should be clearly marked by the international Trefoil symbol on the cabinet of a radiography set so that any person approaching it is aware that it contains radioactive material. The symbol should be to the pattern of BS 3510: 1968. The type and activity of the material should also be clearly marked on the cabinet.

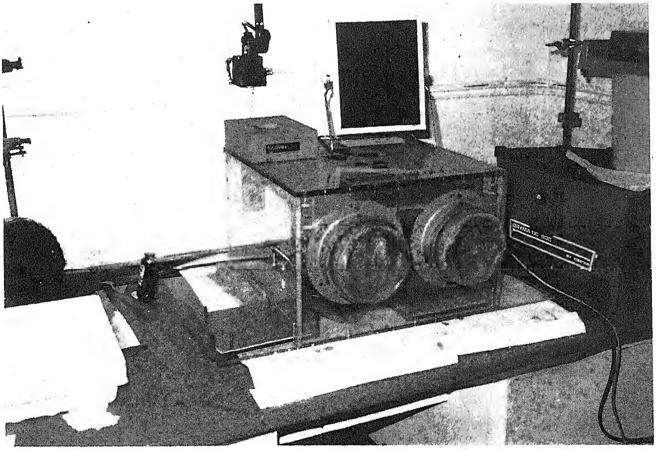

Fig 12 Typical radiography cabinet

Fluorescence

104 For determining the amount and distribution of some filler substances use is made of the characteristic X-ray fluorescence which some materials exhibit when exposed to radiation. The equipment normally used consists of a source within a shielded gun-shaped instrument. The source is close to the open end of the instrument and there is a hand-operated shutter and a detector system designed to measure the fluorescent radiation produced in the material under examination. The radioisotopes used vary according to the material to be examined. The most commonly used are iron 55 and cobalt 57 with activities of up to 20 millicuries (720 M Bq).

105 The shielding of the instrument is sufficient to avoid exposure to a dose rate of more than 0.75 millirem (7.5 μSv) per hour. Nevertheless care should be taken in use to ensure that the useful beam is not pointed at any person or into an occupied area.

106 The presence of radioactive material in an X-ray fluorescence detector should be clearly marked by the international Trefoil symbol so that anyone approaching it will see that it contains radioactive material. The symbol should be to the pattern of BS 3510: 1968. The type of radioactive material and its activity should also be clearly marked.

Smoke detectors

107 For fire detection in storage areas, computer rooms and offices, smoke detectors incorporating a source of ionising radiations are widely used. The detectors incorporate a source of Americium 241 in either sealed or unsealed form with activities of up to 10 microcuries (370 K Bq) in the case of older systems but only 0.5 microcuries (19 K Bq) in modern detectors. Some older systems in use, containing up to 10 microcuries (370 K Bq) of radium 226, are being replaced because the modern systems are more efficient. The action of smoke detectors depends on the alteration of the electrical charge produced in the air around the radiation source when smoke enters the detector.

108 When installed, smoke detectors present no problems and precautions need only be taken during installation and subsequent maintenance or removal. With detectors using Americium 241 care should be taken to avoid damaging the foil containing the isotope. Further precautions should be adopted when handling the older smoke detectors containing Radium 226. These will involve the classification of any persons who might be exposed to a dose rate of ionising radiation in excess of 0.75 millirem (7.5 μSv) per hour. They should be instructed as to the risks involved, the precautions to take and the proper method of working.

Glossary

milli	(m)	one thousandth or 10^{-3}
micro	(μ)	one millionth or 10^{-6}
kilo	(k)	one thousand or 10^{3}
mega	(M)	one million or 10^{6}
giga	(G)	one thousand million or 10^{9}

Alpha particle Nuclear particle of mass 4 units carrying 2 units of positive charge. Will not penetrate skin, and ranges only a centimetre or so in air. Emitted by radioisotopes such as uranium 238, thorium 225, plutonium 238, polonium 210, etc.

Beta particle Nuclear particle of mass 1/1860 units carrying 1 unit of negative charge. Will penetrate skin, and has a range of up to 6m in air. Emitted by many radioisotopes.

Becquerel (Bq) The measure of quantity of radioactivity. A substance has an activity of 1 becquerel (Bq) if 1 atom of it disintegrates every second. This is the new SI unit gradually replacing the curie. 1 Bq equals 2.7 x 10^{-11} curies

Bremsstrahlung Radiation produced by the rapid deceleration of a beta particle, such as when it is caused to bombard a heavy material. The radiation is identical to X-radiation. Bremsstrahlung is therefore an addititional hazard which may arise when handling beta-emitting raioisotopes.

Contamination Radioactive materials released from their normal containment into the working environment. It may be present on working surfaces or airborne.

Curie A measure of quantity of radioactivity. 1 curie of radioactivity is such that 3.7 x 10^{10} atoms of it are disintegrating every second. This unit is gradually being replaced by the becquerel.

eV Electron volts. A measure of energy of a particle or radiation. 1 eV is the energy attained by an electron when accelerated between electrodes which have an electrical voltage of 1 volt between them. Many radioisotopes emit beta particles of energy around 1 MeV, and some others emit alpha particles of energy around 5 MeV.

Element A substance which cannot be chemically decomposed into any simpler substances.

Electron Atomic particle of mass 1/1860 units carrying one unit of negative charge. Differs only from the beta particle in its origin, which is from outside the nucleus of the atom. (The beta particle originates from inside the nucleus.) Electrons can be stripped off from atoms by the application of heat, electrical voltage, mechanical action or bombarding with a nuclear particle. This process is called ionisation.

Gamma ray Nuclear radiation. Will penetrate considerable thicknesses of lead or concrete and has a very long range in air. Emitted by many radioisotopes in association with either an alpha particle or a beta particle.

Half life The time in which half the radioactive atoms present in a given amount of radioactive material disintegrate. The value of the half life is characteristic of a particular radioisotope and varies from millionths of a second to millions of years according to the radioisotope considered.

Ionisation The process by which an electron is stripped from its parent atom. This requires energy and is the means by which the energy from an incident particle or radiation is translated to tissue or human cells.

Neutron Nuclear particle of mass 1 unit carrying no electric charge.

Proton Nuclear particle of mass 1 unit carrying 1 unit of positive charge.

Rad The abbreviation for 'radiation absorbed dose'. A measure of energy deposition in a medium.

Rem The abbreviation for 'rad equivalent man'. A measure of the damage caused by exposure to radiation, and is gradually being replaced by the new unit, the sievert (1 rem = 0.01 Sv).

Sievert (Sv) This is the new SI unit gradually coming into use to replace the rem. It quantifies the equivalent absorbed dose and 1 sievert equals 100 rems.

X-radiation Radiation produced when materials are bombarded with electrons. The process normally takes place in an X-ray tube in which electrons are 'boiled off' from a filament, subsequently accelerated by an electrical voltage and caused to impinge on a target of a heavy metal, often tungsten. See Bremsstrahlung.

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